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Air Carrier Operations and Collaborative Decision-Making Study

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MTR 93W0000244
November 1993
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MITRE Corporation, McLean, Virginia

Abstract

Traffic Flow Management (TFM) is the process by which the Federal Aviation Administration (FAA) balances capacity and demand for National Airspace System (NAS) resources. In the current system, air carriers have little input into the FAA TFM decision-making process, while the FAA must make decisions with little information regarding air carrier rationale. Observations of air carrier information flows and decision-making structure conducted for this study led to the conclusion that improving communication, collaboration, and coordination between the FAA and air carriers regarding TFM can improve NAS resource utilization, and can better satisfy diverse FAA and air carrier objectives. This report describes generic air carrier operational decision making; the effect on air carriers of FAA TFM strategies; and some of the issues associated with improving FAA/air carrier communication, collaboration, and coordination in the TFM decision-making process.

Suggested Keywords: Airline, Collaboration, Decision Making, National Airspace System (NAS) Operations, Traffic Flow Management (TFM)

Acknowledgements

This study would not have been possible without the cooperation of the air carriers contacted. The supervisors and staff we talked with were extremely helpful and patient, and enthusiastically answered our questions.

We would also like to thank Dr. Glenn Roberts for his technical review of our project, Donald Bull for his air carrier expertise, and Elizabeth May for her efficient and careful document preparation.

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SECTION 1 INTRODUCTION

1.1 BACKGROUND AND SCOPE

The Federal Aviation Administration (FAA) is in the process of defining and documenting the operations concept and architecture for the future Traffic Flow Management (TFM) system. The challenge of that system is to organize multiple air traffic flows through busy areas in the National Airspace System (NAS), manage the volume of traffic into and out of congested airport areas, and minimize delay-related problems associated with the continued growth of air traffic while still ensuring safe aircraft separation. In today's system, delays due to Air Traffic Control (ATC) and TFM factors, by some air carrier industry estimates, cost the industry $1.5 billion per year in fuel, crew, and other direct operating costs (Air Transport Association of America, 1992). Indirect costs associated with missed passenger and crew connections, decreased customer satisfaction, and equipment underutilization are more difficult to measure, but are likely to increase this figure.

The FAA has identified a need for greater coordination, collaboration, and data sharing with NAS users (particularly the air carriers) to facilitate TFM decision making (FAA, 1993). In light of this thinking, the Center for Advanced Aviation System Development (CAASD) of The MITRE Corporation began a study of air carrier operational decision making, the operational relationship between air carriers and the FAA, and the potential for increased TFM collaboration; this study was undertaken as part of CAASD's fiscal year (FY) 1993 TFM Mission-Oriented Investigation and Experimentation (MOIE). Because air carriers have the most impact on demand for NAS resources, this study concentrated on air carrier decision making, and the interaction between air carriers and the FAA. Moreover, although the TFM organization at the FAA performs a number of functions in addition to flow management,[1] this report focuses only on flow management decision making.

1.2 STUDY OBJECTIVES AND REPORT PURPOSE

The objectives of this study were as follows:

- To document air carrier operational decision making, internal and external information flows, and decision-making structure related to TFM.
- To describe alternative concepts for improving operational TFM information exchange between the FAA and the air carriers.

- To develop a knowledge base that could be used to provide an air carrier perspective for other TFM MOIE and sponsor-funded activities.
- To establish a closer working relationship between CAASD and the air carriers, which could improve access to the air carriers' view of TFM and provide better insight into their concerns to enhance the FAA's planning process (e.g., the TFM Architecture and Requirements Team [TFM-ART]).

The purpose of this report is to document the study findings. To that end, it describes and analyzes the TFM decision environment. In addition, it identifies opportunities for improving that environment by applying collaborative decision technology, along with details of the associated operational and procedural issues.

1.3 APPROACH

To document air carrier operational decision making related to TFM, information was obtained through visits to seven different air carrier system operations and station operations centers (detailed in Appendix A), representing the spectrum of air carriers. To gain an in-depth understanding of operations, it was necessary both to observe operations directly and to interview air carrier personnel responsible for operations, operational analysis, and scheduling. Additional information was gathered through subsequent phone interviews and through visits by air carrier personnel to CAASD. An analysis of the results of these observations and interviews identified common and distinguishing factors among air carriers, opportunities for technological improvements, and related operational and procedural issues that would need to be addressed. This report is based on that analysis, as well as similar observations and analyses previously conducted by the authors regarding the TFM decision-making environment within the FAA (see Appendix B).

The above observations, interviews, and analyses were also used to contribute to other MOIE and sponsor-funded activities, including the following:

- Participating in meetings with the TFM-ART (FAA, 1993) and air carriers
- Participating in the FAA Operations Research Service's (AOR) FAA/Airline Data Exchange (FADE) Experiment
- Developing air carrier decision heuristics for the TFM Decision-Making Simulation MOIE, another component of the FY93 TFM MOIE project
- Recommending a target domain for applying enabling technology and operational concepts investigated by the Visual Collaboration in Air Traffic Control MOIE (Roberts et al., 1993), and participating in the associated prototype development
- Producing a variety of briefings, memoranda, and informal notes for a broad CAASD audience

An ongoing relationship with the air carriers was established by cultivating contacts with individuals who are responsible for air carrier operations. These contacts continue to serve as sources of information for both CAASD and the FAA.

1.4 AUDIENCE

This report is intended for FAA system developers and operational personnel from the FAA flow management and the air carrier operations community. The reader is assumed to have a general knowledge of ATC and TFM and related terminology.

1.5 REPORT CONTENT AND ORGANIZATION

Section 2 provides background information regarding TFM decisions and the decision-making environment. Section 3 presents some of the details regarding air carrier

decision making by describing a generic large air carrier decision-making organization. Section 4 contains an overview of TFM decision making at the FAA, and describes some of the strategies employed by the FAA and their effect on the air carriers. Section 5 addresses opportunities for improving TFM decision making through increased collaboration, as well as associated operational and procedural issues. Section 6 presents recommendations. It is followed by a list of references and a bibliography. Appendix A shows the air carriers visited for this study, while Appendix B describes a previous field study of the FAA TFM decision-making environment, the results of which were integrated into this report. The report ends with a glossary of acronyms.

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SECTION 2
TRAFFIC FLOW MANAGEMENT BACKGROUND

This section provides background material on the role of TFM in managing the flow of air traffic in the NAS, the relationship between the FAA and air carrier TFM organizations, and characteristics of the TFM decision-making environment.

2.1 ROLE OF TRAFFIC FLOW MANAGEMENT

TFM's role is to facilitate the safe and efficient use of airspace and airport capacity. There are physical and operational limitations (e.g., safe aircraft separation, dynamic weather conditions, controller workload, sector configurations) on the amount of air traffic that can be accommodated in en route and terminal airspace, and at airports. System users (e.g., air carriers, general aviation aircraft, military aircraft) determine when and where they would like to fly, while the FAA's TFM function mitigates contention for airspace and airport capacity. TFM regulates the flow of traffic into and through NAS resources, including fixes, routes, sectors, and airports.

The FAA's objectives for TFM as stated in their operational description of the future TFM system (FAA, 1993) are as follows:

- Ensure the efficient use of NAS resources.
- Provide the greatest possible access to NAS resources.
- Provide equitable access for all NAS users.
- Accommodate user preferences.
- Ensure that traffic at any NAS resource does not exceed that resource's safe capacity.

The observations and analyses documented in this report suggest that accomplishing these objectives requires additional coordination on TFM decisions between the FAA and NAS users.

2.2 RELATIONSHIP BETWEEN THE FAA AND AIR CARRIERS

There are two major groups making TFM-related decisions: NAS users (including air carriers, general aviation aircraft, military aircraft) and the FAA. In making these decisions, both groups work in conjunction with the FAA's ATC function that ensures safe aircraft

separation. As noted earlier, since air carrier operations represent significant blocks of flights that function as major contributors to the flow of air traffic, this study focused on the air carriers' role in the TFM decision-making process. The interface between the air carriers and the FAA determines the nature of their information exchange and collaborative decision making (Figure 2-1). This report describes in detail the nature of this interface and implications for modifying it.

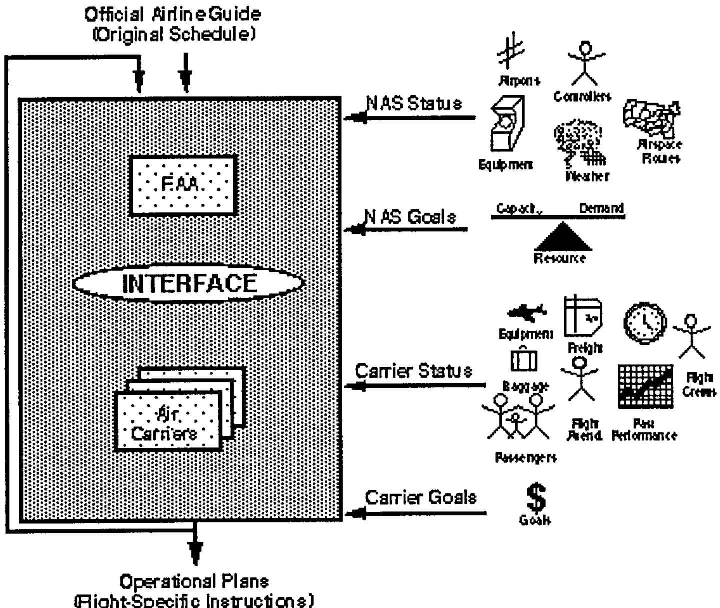

Figure 2-1. TFM Decision-Making Information

The primary input into FAA and air carrier TFM decision making is the air carriers' original schedules. Using these schedules as a basis, the FAA and air carriers interact to produce specific instructions for controllers and pilots regarding individual flights. These instructions concern the intended route of flight and specific arrival, departure, and en route times. Collectively, these individual flight-specific instructions can be thought of as operational plans for each air carrier. The operational plans of individual air carrier operations departments represent attempts to complete as much of the original schedule as possible. Air carriers use their knowledge about the status of their operations (equipment, passengers, crews, freight, etc.), business motivations behind the original schedule, their own goals, and the status of their achievement to make trade-off decisions in formulating these plans. On the other hand, the FAA is responsible for the efficient and safe utilization of NAS resources. The TFM decision makers in the FAA have the most complete knowledge about the status of those resources (equipment, airspace, weather, controllers, etc.). FAA decision makers also have the best understanding of their own goals and the status of their achievement over time.

In today's system, FAA and air carrier information is only partially shared, and thus the decision makers in the TFM system do not all have the same information on which to base their decisions. The current interface between the FAA and air carriers allows for unilateral decisions and communication of chosen options, but very little exchange of information about the inputs, processes, or rationale for those decisions. One analyst with the FAA described the interface as being like that between the two players in the game Battleship[2]: each has only a vague notion of the other's strategy, and is therefore reduced to probing the other (in Battleship with blind shots) to discover that strategy and thereby better predict the other's behavior (Fujisaki, 1993).

Table 2-1 presents the decision options currently available for the FAA and the air carriers to manage traffic flow and manipulate operational flight plans. In today's system, most control is exercised through actions regarding individual flights. The greatest activity occurs

in canceling, delaying, and rerouting individual flights. While canceling and creating flights are solely the prerogative of the air carriers, delaying and rerouting individual flights are options available to both the FAA and the air carriers. However, as discussed above, the two groups base their decisions about taking those options on differing information and goals.

Table 2-1. Current TFM Decision Options

Decision Options	FAA	Air Carriers
Create Flights		X
Cancel Flights		X
Delay Flights	X	X
Reroute Flights	X	X
Control NAS Resources	X	

2.3 CHARACTERISTICS OF THE TFM DECISION-MAKING ENVIRONMENT

The air carriers and the FAA make decisions regarding the flow of air traffic in a highly complex decision environment. Certain characteristics of this environment are given, and cannot be altered by changing the mechanisms, procedures, and policies that govern TFM decision making and the interaction between air carriers and the FAA. These characteristics include the following:

- **Real-Time Operational Decisions**
  - **Dynamic Information.** In the TFM decision-making environment, decisions must be made based on information that changes over time, as the decisions are being made. This characteristic constrains the decision-making procedures and mechanisms used. Special attention must be paid to the rate at which relevant information changes. Mechanisms and procedures are needed to ensure that decision makers are kept up to date with the most current information, and that all decision makers are working with the same information (which, as noted above, is not the case in the current system).
  - **Limited Opportunity Window.** TFM decisions must often be made quickly because the opportunity to effect a solution is usually associated with a short time window.
  - **Predictions.** Decisions must be made regarding future states of the system that can only be estimated based on current data. For example, weather, which often reduces the capacity of NAS resources, cannot be accurately predicted, nor can its precise impact on NAS resources be known in advance.
- **Multiple Mutually Constraining Organizations.** Numerous independent organizations are involved in TFM decision making, and their decisions are often mutually constraining. This situation is further complicated by the fact that the objectives of these organizations differ and often conflict. Consider the example of an airport predicted to be impacted by severe weather. To enable its air traffic controllers to ensure safe separation of aircraft, the FAA reduces the allowable flow of traffic into that airport. In turn, to satisfy customer, maintenance, and crew scheduling needs, air carriers begin their process of cancellations and substitutions. A given air carrier's decision on how much of its schedule to cancel affects other carriers. Together, the air carrier patterns of cancellation and substitution affect the air traffic controllers' ability to ensure safe separation. This in turn may require FAA TFM specialists to revise

strategies for managing the reduced capacity.

- **Stochastic Nature of Traffic Flow.** The flow of air traffic in the NAS is highly complex. The effect of any one action on the overall flow of traffic cannot be modeled with certainty. Thus decision makers are taking actions whose effects cannot always be precisely predicted (Waldrop, 1992).

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SECTION 3
AIR CARRIER TFM DECISION MAKING

This section describes the nature of air carrier decision making in greater detail and presents an overview of air carrier decision-making structures by presenting a generic description of a large air carrier's operational decision making. From the air carrier's perspective, there are four components of an individual flight: (1) an aircraft, (2) a flight crew, (3) a cabin crew, and (4) a reason for having the flight (Beatty, 1993). The reason or motivation for having a flight is most often the revenues produced by the payload (usually passengers) on board. However, other reasons for a flight can include (1) ferrying an aircraft or crew to a particular location in preparation for a future flight, and (2) ferrying an aircraft to a particular maintenance location. Air carriers are constantly monitoring the status of their aircraft, crews, and various other conditions to make decisions regarding which flights to fly, which aircraft to use, which crews to assign, and when to depart. The air carriers have established rather complicated decision-making structures to deal with the complexities surrounding operational decision making.

3.1 DECISION-MAKING PROCESS OVERVIEW

Multiple planning activities are internal to the air carriers. Many of these activities involve scheduling the utilization of limited air carrier resources. Essentially, each air carrier resource has its own schedule. These resources and some of the constraints governing how they can be utilized are as follows:

- **Aircraft Routing.** Most air carrier fleets have multiple aircraft types (e.g., Boeing 767, McDonnell Douglas-80),[3] whose use is constrained by both mission and maintenance requirements:
  - **Mission**. Aircraft must be in specific locations at specific times in order to fulfill service commitments to passengers. The aircraft in position also must be able to fulfill the mission (e.g., have the correct number of seats, appropriate take-off/landing weights, over-water equipment).
  - **Maintenance.** Periodically, aircraft must receive scheduled maintenance. Not all airports are able to perform all maintenance activities; thus the maintenance needs of each airframe must be tracked to ensure that it receives programmed maintenance at the appropriate time.

- **Flight Crew.** Flight crews are certified for specific aircraft and specific operations (e.g., not all flight crews are certified for Category II and III landings). Crew schedules are constrained by FAA regulations regarding on-duty work hours and by negotiated work rules contained in labor contracts.[4]

- **Cabin Crew.** Cabin crews (flight attendants) are required by the FAA on certain flights. Most air carriers certify cabin crews on all of the aircraft in their fleet. Cabin crew schedules are also constrained by FAA regulations and labor contracts.

- **Gates.** Air carriers have a limited number of gates available to them at most of the airports they serve. These gates must be carefully scheduled to ensure that space is likely to be available for arriving aircraft. Initial gate assignments are often designed to minimize the transfer time (baggage and people) at large hub stations.

- **Passengers.** The air carriers construct their flight schedules (e.g., Official Airline Guide) to provide the service desired by paying passengers. A great deal of care goes into determining exactly when and where to make this service available. In many ways, this determination can be thought of as scheduling available passenger seats. Most domestic air carriers have chosen a hub-and-spoke topology for their operations. This topology, while apparently inefficient for ground operations, allows the air carriers to offer the flying public more flights, to more destinations, more often.

While the Official Airline Guide is a schedule of available flights from a passenger's perspective, internal to the air carrier, additional schedules for aircraft, gates, and crews are also constructed. The air carrier's scheduling department integrates the individual schedules for the various resources into a single original schedule that the operations department attempts to complete each day. An individual aircraft's schedule, known as a *line-of-flight*, is constructed by determining the flights flown by a single aircraft each day. Particular aircraft are not assigned to a line-of-flight until one or two days before the actual flight day. Flight and cabin-crew lines-of-flight are developed in a similar fashion. A crew line-of-flight is something an individual crew can fly on a single day, given FAA regulations and contractual constraints. The air carriers use various mechanisms for determining which crews fly which lines-of-flight. Usually, the crews have some input into their original flight assignments.

3.2 TFM-RELATED PROBLEMS AND SOLUTION OPTIONS

A number of events can occur each day that can make an original schedule unflyable. The air carriers' operations departments must then respond with modifications to the original schedule in an attempt to fly as much of that schedule as possible and achieve the underlying objectives related to aircraft, crew, gate, and passenger schedules. The operational plan is the result of all of these modifications to the original schedule. Based on their relative route topologies, fleet sizes, frequency of flights, length of flights, and service orientation, air carriers are faced with different kinds of operational problems and have available different solution options. Thus, not all air carriers have the same interaction with the TFM decision makers at the FAA. Moreover, not all air carriers share the same perspective on the nature of their desired interaction with the FAA.

As an example, some air carriers have a low frequency of flights at some of the airports they serve (e.g., America West [AWA] has two daily flights into La Guardia [LGA]). Additional flexibility in the ground delay substitution process would have little effect on their decision making regarding TFM ground delay initiatives. Their ability to substitute flights is limited because the time interval between flights is usually longer than the delay allocated. Other air carriers may have numerous flights into those same airports (e.g., American Airlines [AAL] has 56 to LGA, not counting the flights of its commuter partners), allowing them to take full advantage of additional flexibility in the ground delay substitution process.

The frequency of flights between city pairs also has a large influence on how decision are made. As an example, SouthWest Airlines (SWA) often has a large number of flights between city pairs (e.g., 32 flights from Dallas Love [DAL] to Houston Hobby [HOU]) (SouthWest, 1993). SWA would prefer to cancel a few flights (especially if they have low load factors)[5] and accommodate passengers on later flights, rather than suffer large amounts of ground delay. SWA is also unique in that it is a large domestic air carrier that does not have a hub-and-spoke route topology.

A suitable operational plan that satisfies various objectives and schedule constraints (internal and external) emerges from a myriad of adjustments and negotiations among multiple organizations within the air carriers. The term "emerges" is used because often no single function or organization actively integrates all of these schedules and synthesizes an optimum operational plan. Instead there is constant communication among individuals empowered to make decisions within the scope of their responsibilities and without the authorization of others. This is how the air carriers remain flexible enough to deal with all the unpredictable things that constantly upset current operational plans. The various organizations involved in the air carriers' operational decision making are discussed in the next section.

3.3 OPERATIONAL DECISION MAKING: FUNCTIONS, ORGANIZATIONAL UNITS, AND STRUCTURE

Air carriers vary in size from the major ones, such as American Airlines with its hundreds of jet aircraft, to small air taxis with less than a dozen propeller aircraft. The carriers' internal decision-making organizational structure, and thus the form of their interaction with the FAA, also varies. However, the decision-making functions of the various air carriers remain relatively similar, even if the allocation of those functions to organizational units differs. While an effort has been made in this report to document some of the detailed observations regarding the organizational structures of the air carriers visited (Lacher et al., 1993), it is beyond the scope here to describe each structure. Rather, this report contains a generic description of a large air carrier's decision-making structure, and the internal and external coordination that occurs. Because the names for various functional units differ among the air carriers, a single consistent set of terminology is used in this description.

Most air carriers maintain an Operations Control Center that oversees the carrier's entire operation. This facility usually contains the generic air carrier functions of System Operations Control, Flight Dispatch, and Crew Scheduling, and may also include Customer Service, Meteorology, and Aircraft Routing/Maintenance. In addition, most carriers maintain a management facility at those airports (also known as stations) they serve. This facility is referred to herein as a Station Management Office. The roles of System Operations Control and the Station Management Office vary, but in general, the stations have relative autonomy for many decisions, especially those having only local impacts (e.g., when delaying a departing flight for 10 minutes for connecting passengers will have no impact on downstream flights). Decisions having larger, system-wide implications are usually handled by System Operations Control. System Operations Control balances competing needs concerning flight dispatch, crew scheduling, aircraft routing, and especially customer service. The relationship between System Operations Control and the other air carrier functions is depicted in Figure 3-1, which also shows the approximate number of positions associated with each function at a large air carrier.

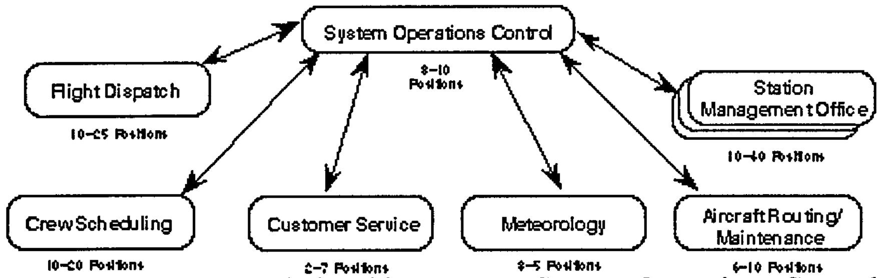

Figure 3-1. Decision-Making Relationship Between System Operations Control and Other Carrier Functions

System Operations Control is formally at the top of an air carrier's operational decision-making hierarchy. It is responsible for coordinating the activities of Flight Dispatch, Aircraft Routing, Crew (Flight and In-Flight) Scheduling, and Station Management, and for planning the air carrier's response to irregular situations. Many air carriers have a subunit of System Operations Control that is dedicated to liaison with the FAA regarding flow management initiatives (e.g., response to ground delay programs, nonpreferred route requests). System Operations Control is often closely aligned with Flight Dispatch. At some air carriers, system operations controllers are also certified dispatchers; at other air carriers, they have a more customer-oriented background (e.g., customer service agent).

By federal regulation, a member of **Flight Dispatch** shares with the captain responsibility for the operational control and safety of each flight. Each flight is assigned to a certified dispatcher. Dispatchers plan the route of the flight, monitor the flight's load (fuel and payload), establish fuel requirements, determine take-off flap settings, and track the flight's progress (Airline Dispatchers Federation, 1993). Each dispatcher is responsible for several flights. The way flights are allocated to dispatchers differs among air carriers: some allocations are based on fleet type, some on a flight's origin, some on its destination. Regulations for commercial flights require that the dispatcher and the pilot be able to maintain direct contact (either voice or data) while the aircraft is airborne. The process and the technology associated with this linkage vary by air carrier and aircraft equipage. Large air carriers can have close to 30 flight dispatch positions.

Crew Scheduling is responsible for ensuring that crews are available to staff each flight. It is divided into Flight Crew Scheduling (pilots) and Cabin Crew Scheduling (flight attendants). Air carriers that are not required to have cabin crews obviously do not have this function. Crew scheduling decisions are constrained by FAA regulations regarding on-duty work hours and by negotiated work rules contained in labor contracts. Crew Scheduling must deal with various irregularities, from a sick crew member to major system delays. It deals with both current flight day issues and planning of future crew schedules.

Customer Service is the unit directly responsible for responding to customer needs. Its major concern is ensuring the transportation of passengers from origin to destination, even if this means putting them on another air carrier. Customer Service protects the air carrier's business interests by ensuring customer satisfaction.

The source of most irregular operations is weather; therefore, scheduling decisions need to be supported with accurate weather data and analysis. The major air carriers provide this support by maintaining their own **Meteorology** departments. Smaller air carriers subscribe to weather data services and train individual dispatchers in meteorology.

Aircraft must undergo routine maintenance based on flight time between maintenance procedures. Maintenance is performed at a limited number of sites. For this reason, **Aircraft Routing/Maintenance** must ensure that a given airframe returns to a maintenance airport when maintenance is needed. Through the flight schedule (which is established mainly on

the basis of marketing considerations), airframes are assigned to an appropriate series of flights so the maintenance rotation can be maintained. As with crew scheduling, when irregularities occur, these carefully laid plans are disrupted, and air carriers must respond.

There is a **Station Management Office** at each airport where an air carrier operates. At hub airports, for major carriers, this management office's operations are large and approach the complexity of System Operations Control. The Station Management Office is typically responsible for all of an air carrier's operations at the airport. At hubs, these responsibilities include operating the ramp tower (which manages ground movement around the gate and loading areas), and coordinating ground activities, including maintenance, baggage handling, catering, cleaning, freight loading, customer service, weight and balance, and refueling. These responsibilities also include gate management and planning at the airport. An example of the organizational structure within a Station Management Office is shown in Figure 3-2.

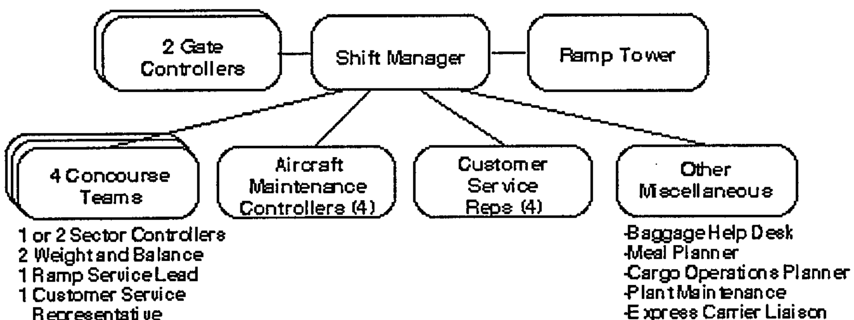

Figure 3-2. Example Hub Station Management Office Organization

3.4 OPERATIONAL DECISION MAKING: INTERACTIONS

Air carrier decision making involves a complex integration of disparate perspectives in response to system irregularities. Organizational decision-making structures such as those of the air carriers have been termed "Decentralized Hierarchical Decision Making"

(Tawfik et al., 1990). This complex type of decision process is distinguished by each organizational unit's independently controlling subsets of the decision variables and objectives and being responsible for its own decisions, which can then serve as input to higher-level decisions. To ensure the emergence of joint decisions, organizational units are governed by coordination procedures or rules of engagement. Decision-making information flows among units at an air carrier to facilitate coordination of actions, not necessarily to effect authorization. For example, although only System Operations Control can officially cancel a flight, a flight may be canceled de facto by other organizational units operating within their own scope. To illustrate, if Crew Scheduling cannot provide a legal crew for a flight, the flight must be canceled.

The various organizational units internal to the air carriers tend to deal with very different kinds of decisions, as suggested by their different titles. For example, the organizational considerations in response to a national ground-delay program would be as follows:

- System Operations Control would make decisions on canceling and moving flights in the schedule in an attempt to minimize the delays experienced by customers.
- The Station Management Office would consider the feasibility of baggage connections and gate assignments under a new operational plan.
- Crew Scheduling would consider the constraints of crew rotation requirements.

- Customer Service would consider how to move passengers between new connections.

The air carrier's final response to a ground-delay program emerges as a product of all these considerations.

3.5 EXTERNAL APPEARANCE OF AIR CARRIER DECISIONS

As discussed above, the air carriers manage multiple internal trade-offs to achieve multiple and in some cases competing business objectives concerning air carrier resources such as aircraft, crews, and gates. However, the external appearance of these decisions (i.e., their appearance to the NAS) can be reduced to four decision options. Table 3-1 expands on these decision options by presenting some internal air carrier rationales that may prompt their selection. The FAA can observe these decision options, but cannot ascertain the underlying business motivations and decisions regarding aircraft, crew, and passenger schedules.

Table 3-1. External Appearance of Air Carrier Decisions

Decision Option from NAS Perspective	Some Rationales That Might Prompt Selection
Cancel Flights	• Start of substitution sequence • Equipment problems (equipment unavailable or needed for another flight) • Crew problems (crew unavailable or needed for another flight) • Weather unacceptable • Delays making the flight unnecessary
Delay Flights	• Arriving passenger/baggage connections • Mechanical problems • Arriving crew delays • Arriving aircraft delays • Fueling delays • Baggage loading delays • Catering delays • Ramp or taxiway congestion
Reroute Flights	• Fuel savings • Weather avoidance • Turbulence avoidance
Create Flights	• Ferrying of aircraft for a later flight or for maintenance at the destination

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SECTION 4
FAA TFM DECISION MAKING

This section describes FAA TFM decision making and the way FAA decisions relate to those made by the air carriers. The FAA TFM decision-making structure, types of decisions, constraints on decision options, and limitations on the decision-making process are discussed.

4.1 TFM DECISION-MAKING STRUCTURE IN THE FAA

The structural organization of TFM decision makers within the FAA is built upon the ATC organizational structure. The FAA has distributed the responsibility for maintaining safe aircraft separation in the contiguous United States to 20 Air Route Traffic Control Centers (ARTCCs). The boundaries of these centers are illustrated in Figure 4-1. For safe separation of air traffic, these centers are further subdivided into many smaller ATC sectors. Separation services in airspace around airports are provided by controllers at Airport Traffic Control Towers (ATCTs) and by Terminal Radar Approach Control Facilities (TRACONs) facilities at the busier airports.

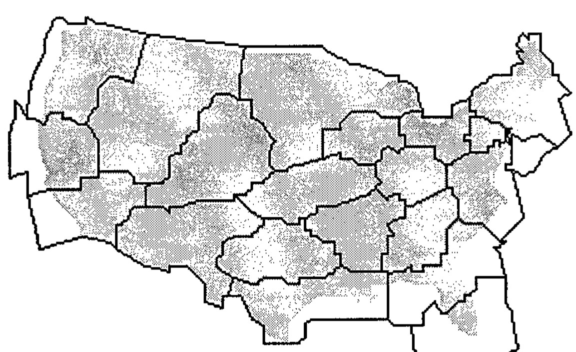

Figure 4-1. Air Route Traffic Control Centers

Building upon this structure, traffic flows within a center are managed by Traffic Management Coordinators (TMCs) in Traffic Management Units (TMUs) at each ARTCC. These *center* TMUs manage traffic flows across all sectors in their center and traffic into and out of their center's airspace. In addition, the busiest airport towers and TRACONs also have TMUs. These *terminal* TMUs focus on the traffic within their immediate vicinity (tower or TRACON airspace). Center and terminal TFM strategies are referred to herein as

local strategies.

The Air Traffic Control System Command Center (ATCSCC) in Washington, D.C. was created in 1970, mainly in response to rising fuel costs, to coordinate nationwide TFM activities. Other events, mainly the Professional Air Traffic Controllers Organization (PATCO) strike of 1981, have contributed to the growth of this facility from approximately three TFM specialists to over a dozen. This is the only FAA facility created for and dedicated to TFM.

Traffic managers in the center and terminal TMUs are known as TMCs and in the ATCSCC as TFM specialists. For the purposes of this report, both are referred to as TFM specialists. The TFM specialists located in the ATCSCC and in each TMU are all experienced Full Performance Level controllers.

Center and terminal TMUs, while managing the flow of air traffic in distinct portions of airspace, tend to make similar kinds of decisions with different scopes. That is, all TMUs are concerned with managing the flow of air traffic through the resources within their airspace and implementing solutions for the adjustment of air traffic flows. TMUs and the ATCSCC make similar kinds of decisions, with similar inputs, and employ similar strategies. This is in contrast to the air carrier decision making, discussed in Section 3, where the various organizational units make decisions regarding very different kinds of air carrier resources (e.g., crews vs. aircraft), involving very different constraints.

Figure 4-2 illustrates the flow of decision-making information and lines of authority among the FAA's TFM organizational units. As with the air carriers, the FAA has "Decentralized Hierarchical Decision Making" (Tawfik et al., 1993). While all TMUs (ARTCC, TRACON, and tower) are loosely under the authority of the ATCSCC, each organizational unit has considerable autonomy regarding the flow of traffic within its airspace. However, the ATCSCC alone has the authority to make decisions that will have multifacility or system-wide impacts. Decision-making information flows between units to facilitate coordination of actions, not necessarily to effect authorization.

It should also be noted that while planning of local TFM strategies and supervision of aircraft compliance with those strategies are carried out by the TMUs, the translation of strategies into specific traffic directives for individual aircraft and the communication of those directives are carried out by air traffic controllers. It is noteworthy that air traffic controllers can modify or disregard TFM decisions if they feel their ability to safely separate aircraft may be compromised.

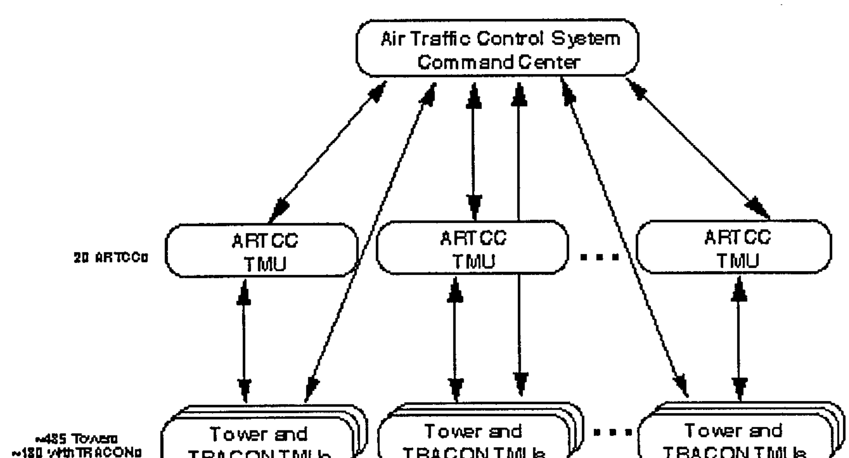

Figure 4-2. FAA TFM Decision-Making Information Flow Structure

4.2 FAA TFM DECISIONS

The strategies described in this section are used by the FAA to manage traffic. The FAA's goal is to accommodate as many aircraft as possible in a safe and efficient manner (i.e., allow air traffic controllers to ensure safe aircraft separation while ensuring effective utilization of available capacity). While the FAA makes decisions to avoid exceeding safe operational limits (i.e., exceed capacity), it also attempts to avoid the underutilization of available capacity at congested resources. The only information the FAA has about individual flights is their planned intentions. The various interlocking schedules (e.g., equipment, crews) and the rationale behind air carrier decisions are part of the air carriers' business decision making and not within the FAA's responsibility. FAA decisions are an attempt to help the air carriers, not hinder their operations. The FAA cannot duplicate the complexity or magnitude of air carrier decision making, nor can it obtain and process all the information available for decisions by each air carrier.

Table 4-1 presents the different strategies that are currently available to the ATCSCC and the TMUs in the ARTCCs, TRACONs, and towers. This table expands on the three basic options presented in Table 2-1. The first two of these options are aimed at reducing flow rates into or through congested NAS resources; the third involves manipulation of the resource itself. These strategies are presented in more detail in Section 4.3, along with their implications for air carrier operations.

Table 4-1. Local and National TFM Strategies

Decision Options	Centers & Local Facilities	ATCSCC
Delay Flights	• Local ground delay program • Ground stop • Approval required (APREQ) for release • Miles-in-trail restriction • Airborne holding • Metering	• National ground delay program • Ground stop
Reroute Flights	• Severe weather avoidance program • Fix load balancing	• National Route Program • Severe Weather Avoidance Program
Control NAS Resources	• Propose resource capacity change • Change operation • Close resource	• Approve resource capacity change

4.3 TFM STRATEGIES AND IMPLICATIONS FOR THE AIR CARRIERS

Some of the strategies shown in Table 4-1 are discussed below, together with their implications for air carrier operations.

Ground delay programs are used when demand for a destination airport is expected to exceed the airport arrival capacity by a significant amount or for an extended period of time. A ground delay program essentially creates controlled departure times based upon originally scheduled departure times (from the Official Airline Guide), so that the planned arrival demand does not exceed the airport acceptance rate (AAR). Accommodations are made in the algorithm for general aviation and other unscheduled flights. The result is a methodical spreading of departure times, and consequently an intended reduction in arrival rates at the

destination airport. ARTCCs can initiate local ground delay programs that delay departures from internal airports and those in immediate surrounding centers (i.e., first-tier centers) if individual delays are less than 30 minutes. The ATCSCC can implement national ground delay programs when assigned ground delays exceed 30 minutes for more than 2 hours (FAA, 1990). Ground delays are communicated to air carrier operations centers in terms of estimated departure clearance times (EDCTs) and controlled times of arrival (CTAs) for each aircraft in their schedule. Carriers are able to substitute CTAs for their own flights or their commuter partner's flights, provided they begin a substitution sequence with a flight cancellation. The ground delay substitution process is currently undergoing significant changes (Sears, 1993).

Ground delay programs significantly disrupt air carrier schedules and operational plans. This is especially true of air carriers having a hub-and-spoke topology. Typically, these air carriers have banks[6] of aircraft arriving within a very short time period (approximately 45 minutes). Typically, arrival banks are followed shortly by departure banks. After the implementation of a ground delay program, the arrival bank can be stretched into hours. This usually has a ripple effect that delays most of the departing flights because of the need to wait for equipment (incoming aircraft), connecting crews, and passengers. Ground delay substitution allows the air carriers limited control and recovery options.

During a **ground stop program**, flights destined for a particular airport, fix, or route are held on the ground until further notice. Ground stop programs are not usually planned in advance, but are an immediate response to unanticipated situations (usually capacity overloads). Such situations can arise when severe weather or an accident suddenly reduces capacity at some resource. At other times, periods of congestion can cause temporary ground stops, which are lifted and reapplied as the situation warrants.

Ground stops severely disrupt air carrier operational plans because there is often little advance warning provided by the FAA, and little information regarding when the ground stop is likely to be lifted. The periodic reapplying and lifting of ground stops is especially frustrating because it produces flights with highly variable departure delays (i.e., some flights with 2-3 hours delay and others with none).

Approval required (APREQ) for release procedures are usually implemented by centers to protect either an internal destination airport, congested route, congested departure fix, or congested sector. Normally, the release authority for a departing flight is the responsibility of the tower. However, during APREQ, towers must first obtain permission from the center (usually in the form of a time window) for approval to release the departing flight. Before granting permission, the center must ensure that the congested resource can accommodate the departing aircraft. Thus aircraft are held on the ground to protect congested resources. Usually, air carriers are not aware that APREQ procedures are in effect until they call for release. Additional information regarding these procedures would assist air carriers in better managing their gates and ramp areas, and might also reduce taxiway congestion (and thus delays).

Miles-in-trail restrictions specify the minimum distance between successive aircraft in a flow bound for a particular destination (usually an arrival airport), on a specific route, over a fix, or across a boundary. These restrictions are used to spread aircraft out in a flow and thus reduce the demand rate. The nature of the restriction puts arriving aircraft into a single queue. A consequence of this is that all aircraft in the flow must slow to the speed of the aircraft at the front of the flow. The class of aircraft subject to the restriction (e.g., all aircraft bound for a given destination) and the details of the restriction (e.g., maintain 20 miles-in-trail) are specified to the sector air traffic controllers, who then translate this information into specific directives for each aircraft under their control. Restrictions are usually placed in 5-mile increments, which minimizes the complexity for air traffic controllers who must implement the restrictions. TFM specialists monitor compliance with restrictions by observing the positions of individual aircraft on a plan view display (PVD).

Air carriers account for anticipated miles-in-trail restrictions by building slack into their schedules to absorb the delay. Some air carriers have reported that because of miles-in-trail restrictions, the scheduled en route time (i.e., time in the air) has increased over the last few years for many city pairs.

Airborne holding halts the forward progress of a flight to delay the flow of traffic by having the aircraft fly in a holding pattern. Currently, the FAA does not plan for airborne holding. However, there are times when its use is unavoidable. As with ground stops, the air carriers have no advance warning, and little related information is provided. Air carrier operations centers usually are aware only that aircraft are in airborne holding; they must rely on past experience to anticipate the duration of the delay. For station operations, this information is important for the prepositioning of ground crews and gate planning. At many large stations, air carriers monitor the air-ground communications frequency to estimate holding times. Aircraft Situation Display (ASD) information assists decision makers at the air carrier operations centers in monitoring holding times. One air carrier has developed a system to intercept Airport Surveillance Radar (ASR) signals and present a display similar to the Bright Radar Indicator Terminal Equipment (BRITE) display available in a TRACON. This helps them determine the airborne holding and internal TRACON vectoring that are likely to be experienced by arriving aircraft.

Many of the air carriers interviewed for this study want some planned airborne holding included in the implementation of a ground delay program. In their experience and based on limited analysis of small amounts of delay, ground delays and airborne holding have a 3:1 ratio. That is, 30 minutes of planned delay would be realized as 30 minutes of ground delay, but only 10 minutes of airborne holding. This is because of the stochastic nature and numerous uncertainties of the system. Many of the air carriers would like to see the FAA plan for approximately 20 minutes of airborne holding during ground delay programs. In the carriers' thinking, the actual airborne holding realized by a flight may be more or less than the planned 20 minutes; however, planned ground delays once taken cannot be removed. The carriers would like to see some hedging in the planning.

In many cases, the FAA has specified routes it prefers air carriers to fly between specific city pairs. Because of weather or prevailing winds, the carriers may determine that alternative routes would save time or fuel. Air carriers must request such alternative routes for each flight individually. The FAA has established the **National Route Program** for dealing with these requests (FAA, 1992). To be approved, every ARTCC affected by the alternative route must give its approval for each flight requesting that route. This program saves the air carriers millions of dollars each year.

Rerouting can also occur because severe weather makes flying the preferred route infeasible. Many ARTCCs have **Severe Weather Avoidance Programs** (SWAPs) that specify various routes. In general, when a SWAP is in effect, all aircraft planning to fly the normal route are affected as a group. Weather reroutes are an important component of both FAA and air carrier responsibilities. Air carriers desire some input into the decision making regarding reroutes. Information concerning reroutes is important for fuel planning, since additional fuel may be required to fly a longer route. Depending on the situation, air carriers may prefer to remain on the ground and wait for a weather situation to move, rather then be rerouted and risk having to divert their aircraft.

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SECTION 5
OPPORTUNITIES FOR IMPROVING TFM DECISION MAKING

Improving the efficiency of TFM is likely to require changing a number of properties of the current decision-making process, including the nature of the interaction between the FAA and the air carriers. These changes may also lead to better satisfaction of individual objectives. Technology can enable such changes, but it is essential that this technology be used to facilitate changes in policies and procedures, not just mechanisms. In addition, there are a number of operational and procedural issues that are interrelated with these changes. This section describes some of the modifiable properties of the TFM decision-making process, potential enabling technologies, and associated issues to be considered.

5.1 MODIFIABLE PROPERTIES OF CURRENT TFM DECISION-MAKING PROCESS

Coordination and Communication. In today's system coordination and communication among decision makers are not an integral part of TFM planning and decision making. Instead, once planning and decision making have been completed, coordination and communication of the decisions require additional steps. For example, once a ground delay program has been planned, a separate communication task is required to send an advisory to affected centers. Furthermore, a phone call must be made to ensure that the center received the advisory and intends to act on it. At the center, when action on the advisory has been taken, another communication is required to inform the ATCSCC, and yet another task is required to enter a description of the action in the daily log.

Within the major air carriers, the situation is better. In many cases, coordination is automatic when an action is taken through the computer system. For example, when the Load and Balance unit has determined the proper distribution of baggage, that distribution is automatically stored in a central database. Ramp applications with access to this database automatically reflect the distribution and inform baggage handlers. Dispatch applications with access to this database also automatically reflect the information in fuel load and flap-setting calculations.

Communication Mechanisms. In the current system, communication mechanisms, both internal and external to the FAA, are limited. The vast majority of communications are verbal, either face-to-face or by telephone. Between the FAA and the air carriers,

communication is either by telephone or teletype.

Data Integrity. Because of the dynamic nature of TFM data, limited communication results in data that is not consistent among decision makers.

Results vs. Rationale. Because coordination and communication are not integral to planning and decision making, the rationale behind those actions is usually not communicated. If one party knows why the other is taking a given action, it becomes possible to predict when that action may be taken again. Otherwise, the rationale must be deduced, and the accuracy of this deduction will affect the ability to predict future behavior. Such hidden rationales are the essence of many "games" (which are discussed further in Section 5.3.3) and serve to exacerbate decision uncertainty and reduce efficiency.

Information Bias. Because of problems with data integrity and the lack of available rationale, it is often assumed that data is biased at the source.

Human Memory. Both the FAA and the air carriers rely greatly on human memory for storing dynamic information, since most communication is verbal. However, while verbal communication is easy and quick, archiving and retrieval are difficult.

Performance Metrics. There is currently no shared set of metrics for evaluating the performance of TFM. The development of such a set of metrics is hampered by two factors. First, the multiple organizations involved in TFM have different goals; therefore they use different measures of their progress toward goals, or have differing perspectives on how to interpret a given measure. Second, given the stochastic and complex nature of TFM, even good decisions can lead to unsatisfactory outcomes on a given day. It is therefore necessary to devise metrics that focus on the quality of the process, not just on outcomes for short-term evaluation. For long-term evaluation, metrics should focus on the long-term trends of outcomes.

5.2 MECHANISMS FOR IMPROVING TFM COLLABORATION

A description of all of the commercial-off-the-shelf technologies that could support improved collaboration in TFM is beyond the scope of this report.[7] However, it is important to note that these technologies currently deal with decision making in terms of only a limited number of business metaphors:

- **Meetings.** This is a major metaphor for collaborative applications, which are aimed at facilitating the meeting process. These applications include those to support voting, brainstorming, and recording of ideas (such as electronic white boards). Such applications support real-time communication between parties at remote locations.

- **Mail.** Applications using this metaphor enable the transmission of data between individuals, with such common mail attributes as delivery times, return receipts, and priorities. Such applications support indirect communication, where the parties may interact with the message at different times and different locations.

- **Bulletin Boards.** These applications are similar to mail, but information is not delivered to a specific address. Instead, it is posted to a common area to which both the sender and recipient have access.

- **Document Handling.** This type of application supports an electronic transaction process, which establishes a sequence of steps through which the document must pass. The application aids in processing and tracking the progress of the document.

The above metaphors may be very appropriate for facilitating collaboration in meetings, design work, or transaction processing; their application to real-time operational environments such as TFM will take some exploration (Roberts et al., 1993). Moreover, there may also be other metaphors on which to base applications for such environments. Given this need for further exploration, however, the collaborative technology implicit in the currently available applications holds great promise for facilitating improved policies and procedures for TFM decision making.

5.3 ISSUES ASSOCIATED WITH IMPROVED AIR CARRIER/FAA COLLABORATION

Regardless of the technology applied, the essential requirement for improving the TFM decision-making process is to enhance collaboration between the FAA and the air carriers by changing policies, procedures, and subsequently interrelationships between the two groups of TFM decision makers. Technology may enable such changes; however, there remain significant organizational issues to be resolved.

5.3.1 Feedback/Dynamics

One issue to be considered is the effect of any change in coordination, communication, or collaboration on the timing and quality of feedback, and consequently on the dynamics of the system response.

Reducing the delay in receiving feedback on decisions can actually lead to a less stable situation (Clark, 1988). Ground delay programs to deal with weather are one possible example. Currently, implementation of such programs requires a relatively long lead time because of the necessary communication and coordination. This provides an inherent constraint on how quickly the system can respond to changes. If this constraint were removed, indiscriminate action could lead to an unstable situation in which delay programs would yield air carrier schedule changes that would yield changes in demand that would yield changes in the delay program, and so forth.

Another issue in the TFM environment concerns the effect of "decision inertia." Analogous to physical inertia,[8] it involves an initial resistance to making a decision until causes requiring action become irresistible. The ground delay decision is one example. The ATCSCC will delay initiating a program because it knows that decision will have widespread impact on the air carriers and the NAS. The ATCSCC also knows, as with physical inertia, that once a decision has been set in motion, it is difficult to stop: given the ground delay program, air carriers begin to rearrange their schedules, canceling and substituting flights.

5.3.2 Uncertainty

Because of the complexity of NAS dynamics, the number of decision makers involved, and the unpredictability of weather, it will always be possible for a "good" decision to lead to unfavorable outcomes. The greater the lead time, the greater the range of possible outcomes is likely to be. It therefore becomes important that the level of detail at which communication and coordination occur match the granularity of the range of possible outcomes at the time of the communication. This suggests, for example, that aggregate flow directives (such as a percent reduction in numbers of flights) would be most appropriate for distant anticipated congestion problems (DeArmon, 1993).

5.3.3 Gaming

An essential feature of games is maintaining the unpredictability of behavior between opponents. As long as the opponent's rationale or strategy is hidden, one must estimate future actions from deductions based on past actions. This may make board games challenging and fun, but it does not lead to efficient management of an already complex and inherently uncertain system.

Behavioral unpredictability can be reduced and efficiency improved by improving the communication of the rationale behind decisions. For example, theoretically, nonpreferred route requests should almost never need to be denied. If air carriers were aware of the rationale for accepting and denying requests, and of the relevant status of NAS resources, they simply would never submit a request that would have to be denied.

One often hides one's rationale in an attempt to control the opponent's behavior. The reasoning is: "Without good predictions of my behavior, he won't as easily be able to satisfy his goals at my expense." This strategy views the system as a "zero-sum" game, wherein any local gain for one must come at the expense of others. However, as in the nonpreferred route example above, there are many instances where win-win strategies can be employed. The challenge then becomes to establish a set of rules and contingencies such that the players' attempts to satisfy their local goals do not lead to global dissatisfaction.

5.3.4 Organizational/Cultural Factors

No change occurs in an organizational or cultural vacuum. The current system has already established certain attitudes and cultural norms, many of which will affect the implementation of improved communication and collaboration.

A history of gaming as discussed above, together with a lack of known rationale, has led decision makers to attribute ulterior motives and personalities (both usually negative) to other organizations. These attributions can be difficult to overcome because they constantly color the way new data is viewed. These biases need to be dealt with explicitly in any transition plan for improving communication and coordination.

In addition, any ongoing operation fosters individuals with an interest in maintaining the status quo. With changes, these stakeholders preceive the loss of power, control, importance, or possibly their jobs. Such stakeholders and their concerns need to be identified, and explicit transition plans made so they will support changes in the system.

5.4 SYNTHESIS

Table 5-1 presents a snapshot of the significant interrelationships among TFM decision-making characteristics (outlined in Section 2.3), properties (Section 5.1), and collaboration issues (Section 5.3). The characteristics (which label the rows of the table) are unchangeable constraints on TFM decision making. The properties (which label the columns) are the attributes that can be changed by changing procedures and policies. In turn, these changes can be facilitated by applying the types of collaborative mechanisms outlined in Section 5.2. Within each cell are the collaboration issues that are impacted by changing the associated

Table 5-1. Interaction of TFM Attributes

Characteristics	[illegible] Performance Metrics	Communication Mechanism	Data Integrity	Joint Decision Making	Human Memory	Results vs. Rationale	Information Bias
Real-time Operations	Feedback Uncertainty Gaming Cultural	Feedback Uncertainty	Feedback Uncertainty Gaming	Feedback Uncertainty Gaming Culture	Uncertainty	Feedback	
Multiple Organizations	Feedback Uncertainty Gaming Cultural	Feedback Uncertainty Gaming	Feedback Uncertainty Gaming Cultural	Feedback Uncertainty Gaming Cultural	Uncertainty Gaming Cultural	Feedback Uncertainty Gaming Cultural	Gaming Cultural
Decentralized Decision Making	Feedback Uncertainty Gaming Cultural	Feedback Uncertainty Gaming Cultural	Feedback Uncertainty Gaming Cultural	Feedback Uncertainty Gaming Cultural	Uncertainty Gaming Cultural	Feedback Uncertainty Gaming Cultural	Gaming Cultural
Dynamic Information	Feedback Uncertainty Cultural	Feedback Uncertainty Gaming	Feedback Uncertainty		Feedback Uncertainty		
Stochastic System	Feedback Uncertainty Gaming	Feedback Uncertainty Gaming	Feedback	Cultural	Uncertainty Gaming	Cultural	

property under the constraints of the associated characteristic. From an experimental design perspective, given the characteristics of the system, the properties can be considered independent variables that can be modified and manipulated, while the issues listed in each square are dependent variables expected to be affected by any change in the properties.

The order of the columns in the table is in terms of decreasing impact from left to right. Changing communication mechanisms would, for example, impact many more collaboration issues than would changing assumptions about informational bias. However, this does not necessarily mean that changing the latter property would be any easier than changing the former. The simple tabular model of Table 5-1 does not represent the effort required to deal with each issue, nor does it represent the interactions among the properties. For example, to change the information bias assumption, one must deal with the difficult task of overcoming well-established organizational/cultural attitudes. In addition, changing the information bias assumption entails changing communication mechanisms, data integrity, and the communication of rationale, not just results.

The above synthesis makes very clear why it is difficult to effect improvements successfully in the TFM system. Each change impacts a set of issues, and the positive impact of a change on one issue can be offset by a negative impact on another. It therefore becomes clear that improving collaboration between the FAA and air carrier organizations requires more than just linking databases together.

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SECTION 6
RECOMMENDATIONS

This section presents a set of recommendations for improving the TFM decision-making process, particularly for improving collaboration in that process between the FAA and the air carriers. In addition, recommendations are made for research and development to support making those improvements.

6.1 RECOMMENDATIONS FOR IMPROVING THE TFM DECISION-MAKING PROCESS

6.1.1 Match Decision Scope with Granularity of Available Information

From the discussion in this report, it seems clear that whatever specific operational concept is implemented for TFM, a major improvement is needed in the match between the scope of decisions and the granularity of available information. This improvement is more one of policy and procedure than of technology. Communication, coordination, and collaboration technologies merely provide a means for implementing more effective organizational policies and procedures; implementation of new technologies without the associated organizational changes historically has not been shown to improve efficiency.

The FAA needs to be given full responsibility for determining capacities of and constraints on NAS resources. It should be responsible for setting the limits on traffic flows into and through those resources. However, observations of air carrier operations conducted for this study (as described in Section 3) indicate that information on the dynamic process of adjustment and negotiation of schedules that underlies an air carrier's operational plans cannot feasibly be communicated to or practicably used by the FAA. Therefore, it seems that within the resource constraints set by the FAA, the scheduling and routing of individual flights needs to be left to the air carriers.

6.1.2 Provide More Efficient Communication and Coordination Capabilities

A considerable amount of groundwork is needed to provide even a foundation for

restructuring operations along the above lines and improving communication, coordination, and collaboration between the FAA and air carrier organizations.

Within the FAA, more efficient mechanisms are needed to improve communication, which, as discussed in Section 5, is a property of the TFM decision-making process that has a major impact on collaboration issues. Improved communication and coordination capabilities need to be integrated into the full range of TFM planning and decision-making tasks.

Improved communication and coordination will increase information available for decision making and facilitate wider participation in the decision-making process. In addition, it will reduce redundant communication tasks and provide more time for strategic planning. It will also increase the situational awareness of decision makers as relevant information becomes more readily available. Furthermore, it will improve record keeping and retrieval, and in so doing, help provide better analysis of the TFM system for further improvement.

6.1.3 Analyze the Interactions Among Characteristics, Properties, and Issues

While the above foundation work is being implemented within the FAA, the interactions among the characteristics, properties, and issues shown in Table 5-1 need to be analyzed to provide a basis for evaluating various operational concepts for TFM decision making.

As better knowledge becomes available to guide development, technology needs to be introduced to improve communication, coordination, and collaboration between the FAA and the air carriers. Particular attention should be given to the technology gap that exists between the different classes of air carriers.

6.2. RESEARCH AND DEVELOPMENT

Efforts to resolve how changes in communication, coordination, and collaboration will impact the various organizational issues described in Section 5.3 will need to proceed simultaneously along a number of avenues. These include empirical analysis, research into other domains with similar characteristics, proof-of-concept demonstrations, and laboratory experimentation (e.g., human-in-the-loop and computer simulations).

These efforts can result in specific recommendations regarding near-term initiatives and modifications to ongoing development programs. In addition, they can support the development of long-term infrastructure development and transition recommendations.

To research current operations and further identify operational and procedural issues, visits to FAA operational facilities will be essential. A proper analysis cannot be done from available documentation of formal procedures alone. Field visits will provide unique and necessary observations of important informal as well as formal operations and procedures. Stakeholders, motives, and concerns (discussed in Section 5.3.4) are almost impossible to identify without extensive direct interaction with the user community. Methods and techniques used to support decision making in the field need to be identified as well.

Many issues cannot be resolved in the field because of the constraints of the current operational system. Therefore, field research must be supplemented with laboratory research that will allow systematic manipulation of the essential factors affecting NAS behavior. Such laboratory research includes human engineering research to evaluate how various communication and collaboration technologies affect the way people acquire and use information for making decisions. This type of research will provide details on how individuals actually perform their tasks.

In addition, computer simulations can allow evaluation of the performance of NAS reliability at a more macro level, and observation of behavior over simulated months or years. Current work suggests that even the dynamic behavior of decision makers (guided by the human engineering research) can be integrated into these simulations.

This convergence of multiple research approaches will make it possible to prove thoroughly the value of new operational concepts as regards their impact on the range of issues presented in this report.

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APPENDIX A
AIR CARRIERS VISITED

Air Carrier	Aircraft *	Flights *	Distinguishing Characteristics	Locations Visited
American (AAL)	675	2700	Large international hub-oriented carrier Average flight ~ 2 hour Relatively high level of automation	Operations Center DFW Station
AMR Eagle	n/a	1800	Four separate express carriers wholly owned by AMR Similar automation to AAL Collocated with AAL Highly hub-oriented Average flight ~ 1 hour	Operations Center DFW Station
America West (AWA)	85	650	Mid-size hub-oriented carrier 53 stations (national network) Low frequency to East Coast No weather unit	Operations Center, PHX Station
Atlantic Southeast (ASA)	70	500	Delta regional express carrier Delta ownership) Highly hub-oriented Little automation Average flight ~ 1 hour 2 Dispatchers, 1 Coordinator No weather unit	Operations Center ATL Station
Delta (DAL)	560	2872	Large international hub-oriented carrier Average flight ~ 2 hours Relatively small operations facilities for number of aircraft/flights	Operations Center ATL Station
SouthWest (SWA)	150	1400	Not hub-oriented, no banks/complexes Average Flight < 1 hour High frequency of flights Increasing automation High aircraft utilization	Operations Center DAL Station
United (UAL)	516	2100	Large international hub-oriented carrier Average flight ~ 2 hours Relatively high level of automation Emphasis on wide-body flights	Operations Center ORD Station IAD Station

* Figures in this chart are approximate and change frequently. They are included to indicate the relative size of each air carrier visited.

APPENDIX B
FAA FIELD STUDY OVERVIEW

Much of the observation and many of the analyses of operations within FAA TFM organizations that have been integrated into this report were conducted by the authors during a prior field study. This section outlines that earlier study and summarizes its results.

Limited documentation of actual TFM operations was available for review prior to the

earlier efforts. What documentation was available did not prepare the investigators for the elegance of operations developed in the field under current procedural and technological constraints.

The field study involved more than 100 hours of observations at the ATCSCC and over 150 hours of observation at ARTCC, tower, and TRACON TMUs. The TMUs at the 5 ARTCCs visited were in environments that were representative of a cross-section of the 20 ARTCC TMUs in the contiguous United States. Denver Center (ZDV) has one main airport and relatively light en route traffic. Washington Center (ZDC) has three major airports and major en route traffic. New York Center (ZNY) has five metropolitan airports and is a gateway for oceanic traffic across the North Atlantic. Within Los Angeles Center (ZLA), there are six major airports and many flights that are internal to the center. Atlanta Center (ZTL) has two major airports, one of which is a major hub for a major air carrier and a regional air carrier; Atlanta also has significant en route traffic.

Most of the time at these facilities was spent observing operations and conducting unstructured interviews with staff for explanation of observed operations. In addition, a "paired problem solving" task was performed at two of the ARTCC TMUs. In this task, the researchers worked with one veteran TMC to devise a TFM problem situation. This TMC then presented the problem to a colleague, and played the role of "game master" to create an environment for the colleague to act out how he or she would solve the problem. This

off-line task allowed the researchers to ask questions about operations independently of the real-time pressures of the actual job. The results of this structure task verified the real-world observations and conclusions. Finally, cognitive characteristics of the ARTCC TMCs were assessed by administering the Myers-Briggs Type Inventory (these characteristics are not explored in this report).

The results of this field study have been presented in briefings and integrated into this report. These results can be summarized as follows:

- Despite operational limitations and technology constraints, a highly competent and effective FAA TFM system has evolved.
- Currently, most of the TFM-related information exchanges among FAA TFM decision makers and with NAS users are limited and are accomplished using unsophisticated technology. Almost all strategic negotiation and conferencing is performed using voice telephones. The ATCSCC uses a teletype network to send formal advisory messages to the center and terminal TMUs and the air carriers. Most air carriers' tactical information is also shared with the FAA via a teletype network. There is a stream of tactical data (mainly aircraft position reports) that is distributed by the FAA to 11 major air carriers via a satellite network (i.e., the Aircraft Situation Display data that is part of the Enhanced Traffic Management System).
- TFM specialists spend a large amount of time communicating and coordinating information. There is a great deal of redundancy in communications, due mainly to the unreliability of the communication mechanisms. The term unreliability is used here not to refer to the communication service itself, but to the total end-to-end linkage that ensures that the sender's intended message reaches the receiving party.
- TFM specialists spend a large amount of time on clerical and record-keeping tasks. Much of the record keeping is done manually; handwritten logs are usually kept. A primary component of these logs is the recording of communications received and sent.
- There is a high reliance on human memory for both static and dynamic information.

- Inaccurate and outdated information from multiple data sources is used to make decisions.

GLOSSARY

AAL	American Airlines, Inc.
AAR	airport acceptance rate
AOR	Operations Research Service
APREQ	approval required
ARTCC	Air Route Traffic Control Center
ASD	Aircraft Situation Display
ASE	Atlantic Southeast
ASR	Airport Surveillance Radar
ATC	Air Traffic Control
ATCSCC	Air Traffic Control System Command Center
ATCT	Airport Traffic Control Tower
ATL	Atlanta International Airport
AWA	America West Airlines
BRITE	Bright Radar Indicator Terminal Equipment
CAASD	Center for Advanced Aviation System Development
DAL	Dallas Love Field
DFW	Dallas/Ft. Worth International Airport
EDCT	estimated departure clearance time
FAA	Federal Aviation Administration
FADE	FAA/Airline Data Exchange
HOU	Houston Hobby Airport
LGA	La Guardia Airport
MOIE	Mission-Oriented Investigation and Experimentation
NAS	National Airspace System
PHX	Phoenix Sky Harbor International Airport
SWA	SouthWest Airlines
SWAPS	Severe Weather Avoidance Programs
TFM	Traffic Flow Management
TMC	Traffic Management Coordinator
TMU	Traffic Management Unit
TRACON	Terminal Radar Approach Control Facility
ZDC	Washington ARTCC
ZDV	Denver ARTCC
ZLA	Los Angeles ARTCC
ZNY	New York ARTCC
ZTL	Atlanta ARTCC